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Fermilab
Accelerator Division
Linac Department

Design of a Beam Absorber Diagnostic

for the Determination of RF Phase and Amplitude Settings

Fermilab Report - Linac Upgrade Note - 189

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I. Overview:

This diagnostic consists of a graphite rod of a known length which serves as a very specific energy filter. By studying the amount of beam current which is transmitted through the graphite, the phase and amplitude of the RF in each of the CCL modules of the Linac Upgrade can be approximately set to the design values. At that point, Phase Scan Signature Matching[1] can be used to more accurately set the RF parameters.

The diagnostic will be placed at the end of the 400 MeV beam line to the straight dump, at a location just outside of the dump. A toroid placed at the entrance and at the exit of the diagnostic will detect the amount of current transmitted through the graphite.

In practice, the phase of a module would be scanned and the transmitted current measured to produce a curve similar to Figure #1. The shape of the curve can be distinguished by three regions: 1) where all of the beam is included in the stable separatrix area, corresponding to full acceleration by the module; 2) only a portion of the beam is within the separatrix; and 3) no beam is within the separatrix. The phase where 1/2 of the beam is accelerated (on the right hand side of the transmission curve) is referred to in this paper as the HWHM (Half Width - Half Maximum) point. The actual measurement however would be of the Full Width - Half Maximum of the curve.

The original idea for this device was provided by Petr Ostroumov of the Institute for Nuclear Research of the Russian Academy of Sciences. To simulate the beam dynamics of the Linac Upgrade, the code LANA (Linear Accelerators Numerical Analysis) written by Dmitri Gorelov (INR) was utilized.

II. Design Parameter #1 - Cutoff Energy:

Early calculations showed that the distance from the synchronous phase (0 degrees) to the HWHM depended upon the energy cutoff limit used. Figure #2 shows the fraction of beam accelerated through Module #1 for three different particle cutoffs in beta (v/c) : within 10%, 8%, and 6% of the nominal value of 0.5094 (152.1 MeV). Figure #3 shows the HWHM vs Cutoff Energy for Modules #1, #3, #5, and #7.

The goal is to find a Cutoff Energy which provides the best precision of phase setting if the exact RF amplitude is known. As can be seen in Figure #3, as the energy cutoff decreases (the energy below the nominal value for the module increases), the position of the HWHM increases fairly smoothly and then reaches a point at which it begins to rise significantly. This change corresponds to the appearance of a shoulder on the transmission curve (as seen in Figure #2 for beta within 10% and large values of module phase). On the basis of these plots, the cutoff energies shown in Table #1 were chosen.

III. Design Parameter #2 - Absorber Material:

There are two main considerations driving the choice of the absorber material. The first is the amount of radioactivity induced in the beam absorber. To make an absorber of a given cutoff energy, a higher density material will reduce the length of the absorber necessary. Unfortunately, higher Z material will also have higher residual radiation dose rates. From Figure 7.9 of Patterson,[2] copper will have roughly a factor of 25 larger dose rate than carbon after activation by 600 MeV protons. Barbier[3] Figure IV.25 also shows copper having a factor of 60 larger dose rate than carbon after activation by 50 MeV protons. Barbier also has shown that the production of activity in most materials is nearly independent of incident proton energy over the range 50 to 2900 MeV. However both of these measurements are for saturation conditions, i.e. bombardment by a constant flux of protons for a long amount of time. A simple calculation for copper indicates that a 10 mA beam of 1 μs length at 15 Hertz for 10 minutes would produce a dose rate on the order of 1 R/hour at a distance of 1 meter. This is clearly at a level that could cause some problems.

Rather than be forced to deal with the possibility of nasty radiation problems, the choice was made to use graphite rods instead of copper. Graphite rods can be machined to the same tolerances as copper. The only other major material concern is the ability to withstand the heating due to energy deposition by the beam. Measurements made by Mike Foley (AD/Mechanical Support) have shown that the graphite rods typically used in the Fermilab machine shop (purchased from The Carbon/Graphite Group Inc. of St. Mary's, Pa.) have sufficient thermal conductivity to transfer heat over a distance of a few centimeters to a water-cooled copper holder. From a sample piece of the graphite, the density was measured to be 1.80 g/cm^3.

IV. Absorber Lengths - Final Design:

To determine the required lengths of graphite needed to stop particles below the cutoff energies listed in Table #1, the program TRIM (TRansport of Ions in Matter) was used. This program was developed by James Ziegler (IBM-Research) and calculates the penetration of ions into solids. The code runs on any DOS based PC having an Intel mathematics co-processor. It typically takes a few hours to obtain 5000 ion histories on the Gateway 2000 PC. The length needed to stop 95% of the particles having the Cutoff Energy is given in Table #2.

The proton range is very sharp as shown by the data in Table #3. For a length of 8.384 cm of graphite, 5% of the particles having an energy of 137.1 MeV will be transmitted through the graphite, however if the energy of the particles is increased by 1% to 138.5 MeV then 94.4% will be transmitted.

In order to reduce the size of the diagnostic (and thus the cost) the carbon rod is divided into segments for each module of the Upgrade. The final design is shown in Figure #4. For Module #1, only one segment is moved into the path of the beam, the segment furthest downstream. For Module #2, the next segment upstream is also moved into the beamline, and so on. Since the majority of the energy deposition occurs in segment #1, it is the only portion to require water cooling. Each segment can be moved into position manually. The lengths of the segments are: 8.384, 4.441, 4.687, 6.229, 6.217, 7.787, and 7.528 cm.

V. Dependence of HWHM upon RF amplitude:

The original premise of the diagnostic was to determine the phase setting of the RF for a module assuming that the RF amplitude is known. However as Figure #5 shows, there is a very linear response in the HWHM versus RF amplitude. If the HWHM can be determined to within a degree then the RF amplitude can be set to within 1%.

VI. Conclusions:

These calculations have shown that a beam absorber can provide a means of determining the field amplitude and phase for linac tanks. In particular, a graphite absorber has been designed to tune modules of the Linac Upgrade during commissioning.

Module #	Enominal - E (MeV)	Nominal Energy (MeV)	Cutoff Energy (MeV)
1	15	152.06	137.06
2	15	189.97	174.97
3	20	229.78	209.78
4	20	271.08	251.08
5	25	313.64	288.64
6	25	357.13	332.13
7	30	401.46	371.46

Table #1 - Determination of Cutoff Energy for Beam Absorber.

Rod #	Cutoff Energy (MeV)	Length (cm)
1	137.06	8.384
2	174.97	12.825
3	209.78	17.512
4	251.08	23.741
5	288.64	29.958
6	332.13	37.745
7	371.46	45.273

Table #2 - Length of Graphite Rod required to stop 95% of particles having an energy of the Cutoff Energy.

E/Ecutoff	% Transmission Length = 8.368 cm	% Transmission Length = 8.373 cm	% Transmission Length = 8.384 cm	% Transmission Length = 8.405 cm
0.99	0	0	0	0
1.00	10	8	5	2
1.01	97	96.4	94.4	87.1
1.02	99.7	99.7	99.7	99.7
1.04	100	100	100	100

Table #3 - Variation in Transmission with Energy and Length of Graphite Rod.

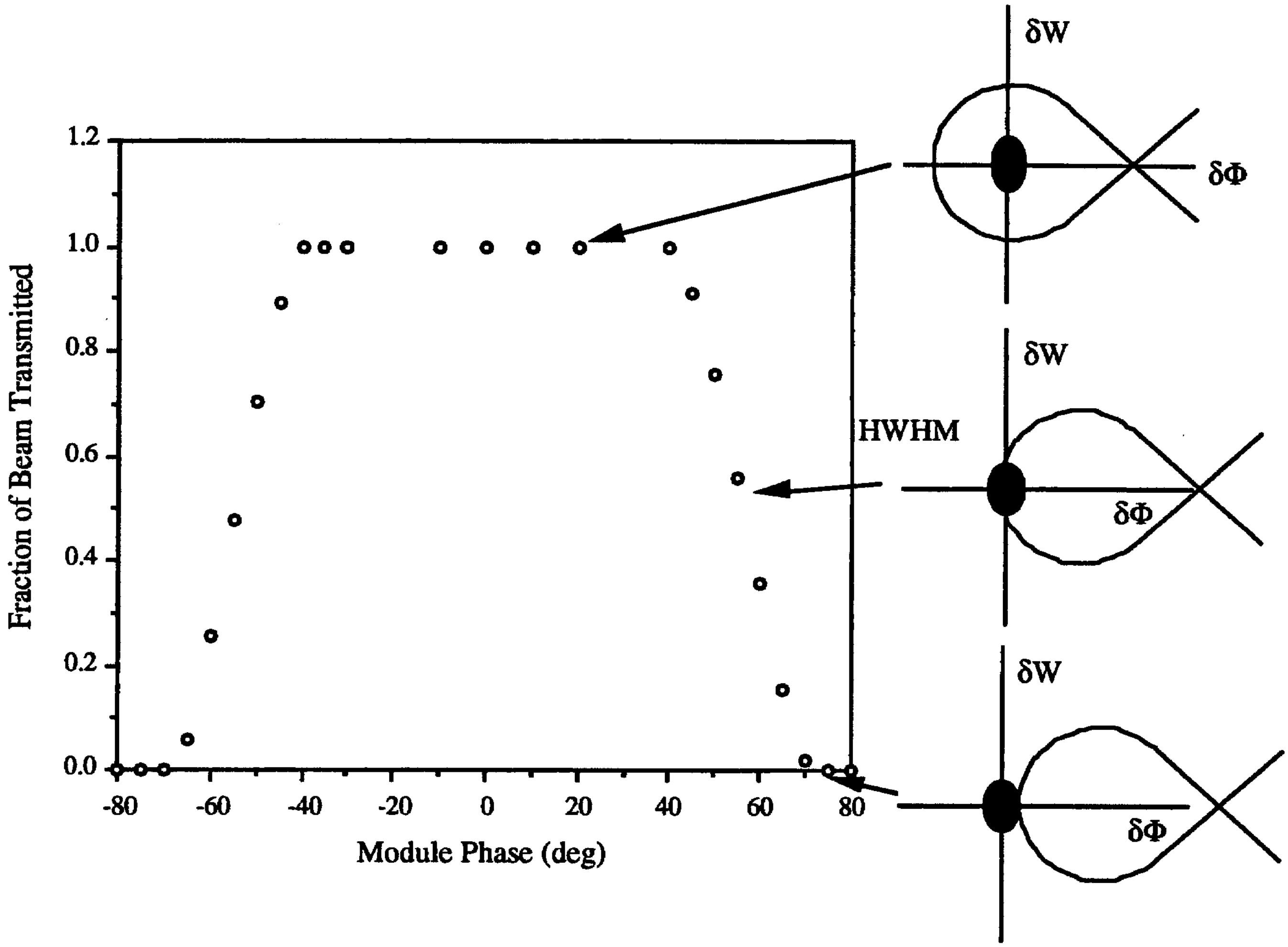

Figure #1 - Schematic Diagram of Phase Scanning a CCL Module and the Output of the Beam Absorber Diagnostic.

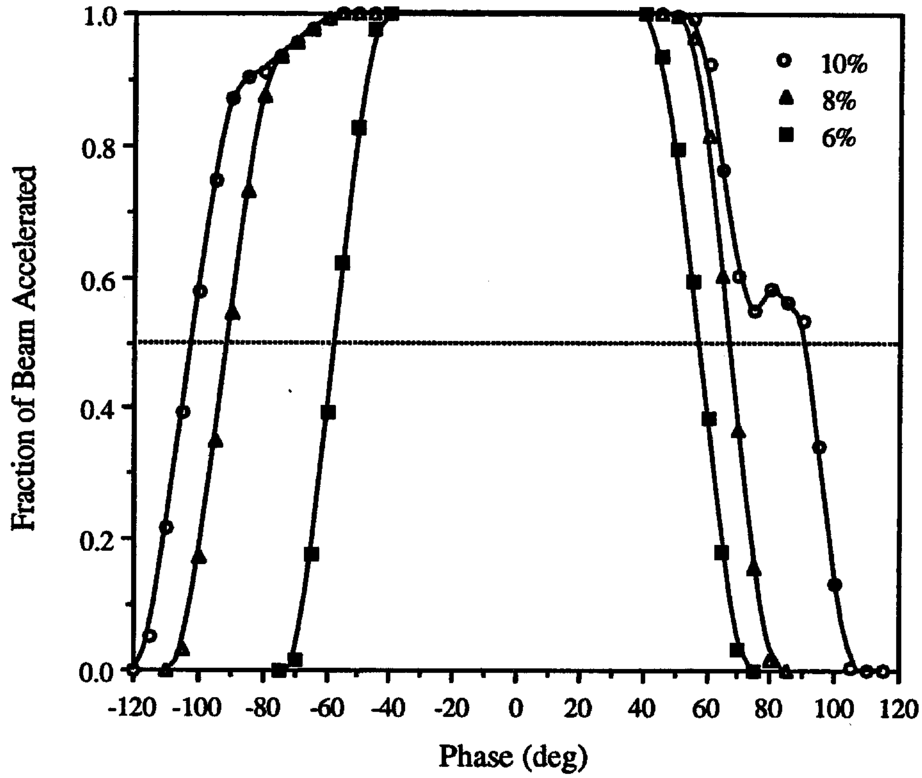

Figure #2 - Fraction of Beam Accelerated versus RF Phase for 3 cutoff levels of particle beta - CCL Module #1.

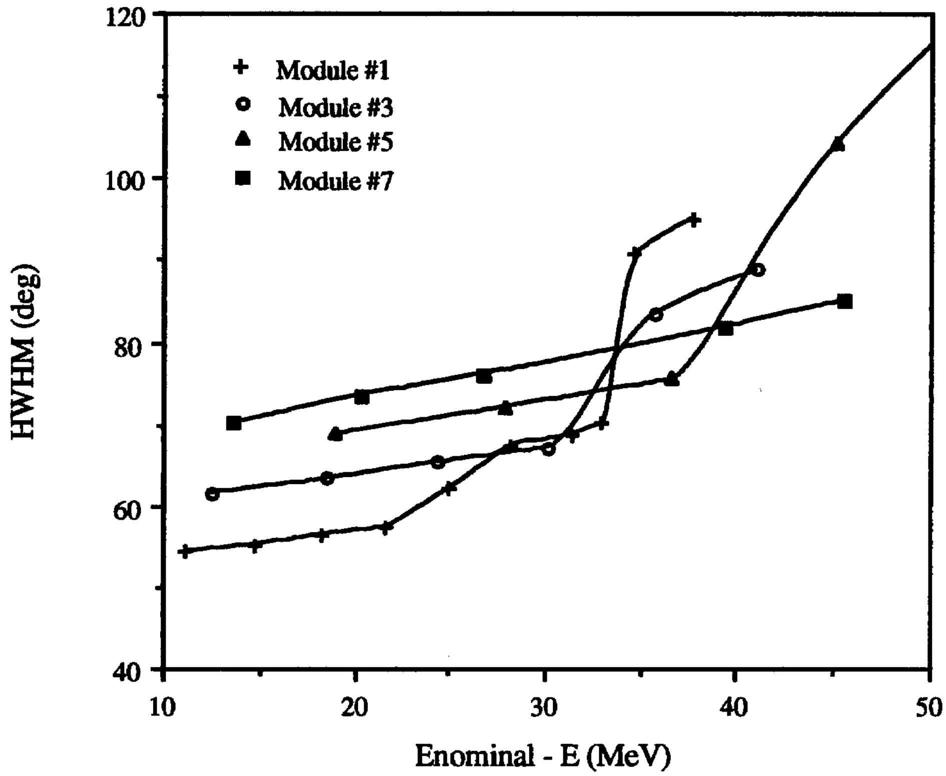

Figure #3 - HWHM versus Energy below nominal for Modules #1, #3, #5, #7

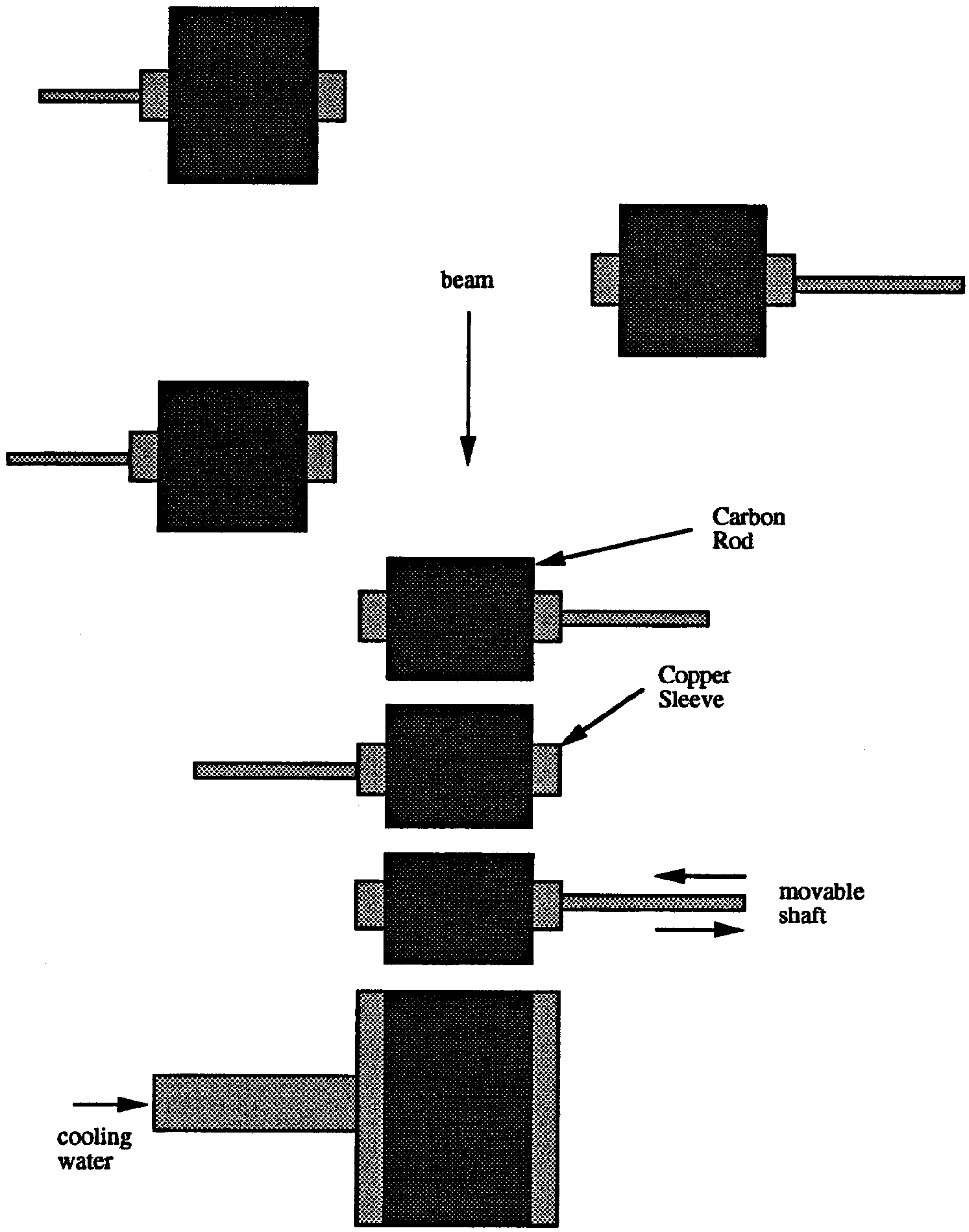

Figure #4 - Schematic Design of Beam Absorber Diagnostic (top view - not drawn to scale).

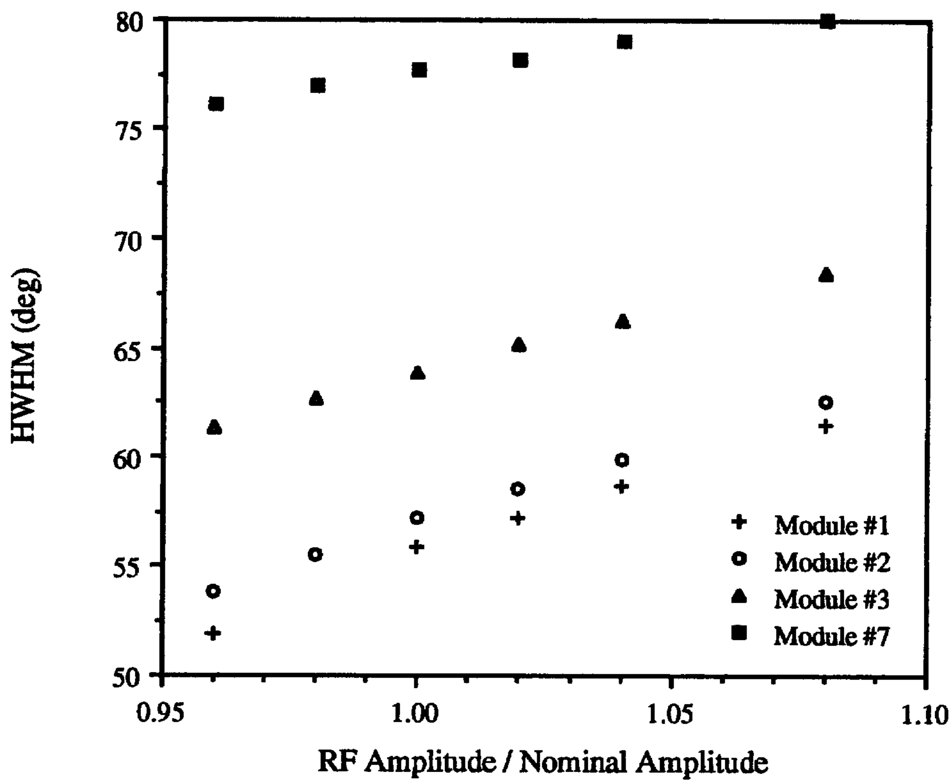

Figure #5 - HWHM vs RF Amplitude for Modules #1, #2, #3, and #7.

References:

[1]"Phase Scan Signature Matching for Linac Tuning", T.L. Owens, Fermilab Report LU-186, November 1992.

[2]Accelerator Health Physics, H.Wade Patterson and Ralph H. Thomas, 1973.

[3]Induced Radioactivity, M. Barbier, 1969.